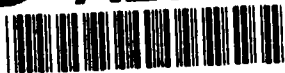


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REPORT NO TN95-2

**SUSTAINING THE HEALTH
AND PERFORMANCE OF
SOLDIERS/WARFIGHTERS DEPLOYED
TO HARSH ENVIRONMENTS**

**U.S. ARMY RESEARCH INSTITUTE
OF
ENVIRONMENTAL MEDICINE
Natick, Massachusetts**

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**UNITED STATES ARMY
MEDICAL RESEARCH & MATERIEL COMMAND**

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WARFIGHTERS DEPLOYED TO HARSH ENVIRONMENTS**

Prepared by

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November 1994

**U.S. Army Research Institute of Environmental Medicine
Natick, MA 01960**

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EXECUTIVE SUMMARY

This report describes the contributions, core competencies and capabilities of the U.S. Army Research Institute of Environmental Medicine and this Institute's commitment to protect, sustain and enhance the health and performance of the soldier. The Institute's mission focuses on two of the four major threats to the warfighter; environmental and occupational. The significance placed upon environmental threats is described in Army Field Manual 100-5, June 1993: "... U.S. Army forces must be prepared to fight and win on short notice anywhere in the world, from blistering deserts, frigid wastelands, in rain forests, tundra, mountains, jungles and swamps ..." Environmental threats to the individual soldier are addressed with militarily relevant historical discussions of injuries and casualties incurred by military forces operating or deployed to harsh environments of extreme heat, cold and high terrestrial altitude within the research disciplines of thermal and altitude physiology and medicine. Occupational threats are presented in relationship to the dimensions of individual's physical capacity, physical and cognitive performance and the multi-stressors associated with continuous and sustained operations. The impact of these threats is studied within the research disciplines of military occupational physiology and physical performance; occupational medicine; military performance and neuroscience; and military nutrition. The products of this research Institute draw heavily upon the knowledge gained by its medical research staff over the past forty years in laboratory and field studies and by scientists and engineers that have accompanied troops deployed around the world in training, peacekeeping and combat operations.

BACKGROUND

The U.S. Army Research Institute of Environmental Medicine (USARIEM), a subordinate of the U.S. Army Medical Research and Materiel Command, was activated in Natick, Mass., in 1961, as a composite of elements from former medical (Armored Medical Research Laboratory (AMRL), Ft. Knox, Ky.) and quartermaster (Climatic Research Laboratory (CRL), Lawrence, Mass.) laboratories (7). The establishment of USARIEM fulfilled the vision that both medical and clothing research would be collocated and integrated to maximize scientific return for the government's financial investment. This vision remains today in that USARIEM is collocated as a tenant organization with its host the U.S. Army Natick Research, Development and Engineering Center (NRDEC) (7).

Another important predecessor of USARIEM was the Harvard Fatigue Laboratory in Cambridge, Mass., a civilian laboratory formed in response to climatic problems encountered by armed service personnel during the First and Second World Wars. Its investigators were the first to use a multi-disciplinary (physiology, biochemistry, medicine, and psychology) approach to study human adaptations and work/performance capabilities and limitations at environmental extremes (8). Today USARIEM investigators continue to employ this unique multi-disciplinary approach to solving problems faced by today's warfighters.

MISSION

USARIEM's mission focuses on two of the four major warfighter threats, environmental and occupational. The Institute conducts basic and applied research in environmental pathophysiology; physiology and medicine; biophysics and biomedical modeling; and occupational health and performance. Environmental research focuses on sustaining, protecting and enhancing the health and operational performance of United States forces exposed to extreme heat, severe cold, and high terrestrial altitude. Occupational health and performance research focuses on: occupational physiology/physical performance; occupational medicine; military performance and neuroscience; and military nutrition; to sustain, protect and enhance warfighter performance.

Historical accounts, climatological data and topographical perspectives of environmental threats to military forces are a testament to the impact of environmental extremes on military operations.

HEAT

During World War II, over 35,000 American soldiers required hospitalization for heat injuries, and 238 of these soldiers died. More recently in Grenada, 29-48/1000/soldier days were treated for heat-related injuries at Battalion Aid Stations (9). During training in desert climates, 7/1000/soldier days are treated for heat-related injuries compared with 15/1000/soldier days during training in tropical climates (9,10). If a military force does not implement proper hot-weather doctrine, the effects can be devastating; for example, 20,000 Egyptians suffered heat-related deaths during the six-day 1967 war with Israel (9,10).

Another perspective of the potential for heat injury is seen from climatological data. Assuming that acclimatized soldiers in Battle Dress Uniform (BDU) are performing light to moderate work, approximately 52% of the global land area has the potential to cause heat injury. This land area percentage would increase substantially if chemical protective posture (MOPP) scenario is assumed. In addition to nearly continuous heat-stress conditions within equatorial regions, the Northern and Southern Hemisphere summers extend environmental heat-stress conditions well into the North and South temperate latitudes (6). Militarily important geo-political regions with significant heat-injury potential include Central America, South America, Africa, Southeast Asia, Southwest Asia and the Middle East (6). Physical and mental performance are degraded with heat stress; incapacitating heat injuries include heat cramps, heat exhaustion, and heat stroke, a life-threatening illness.

COLD

In 1982, the British evacuated 495 cold injuries (4.7% of the force) from the Falkland Islands. During World War II, American forces suffered 90,000+ cold injuries, representing 10% of the total wounded in the war. Those 90,000 injuries resulted in 7,500,000 man days lost from combat, the equivalent of one division lost from combat for 17 months. This is particularly significant since the mean air temperature recorded

was -1°C when these injuries occurred, and some 60% of the earth's land mass is located in an area where the January low temperatures are below 0°C . Furthermore, over 25% of the land mass is located in regions of the earth experiencing mid-January low temperatures below -18°C (6).

Climatological data provides another perspective of the cold environmental threat. Approximately 30% of the global land area has the potential to cause cold injury. In addition to nearly continuous cold stress conditions within the Arctic and Antarctic regions, the Northern and Southern Hemisphere winters extend environmental cold-stress conditions well into the North and South temperate latitudes (6). High terrestrial altitudes also increase cold-stress even in temperate latitudes. Militarily important geo-political regions with significant cold-injury risk potential include Eastern Europe, North America, South America and Asia. Incapacitating injuries include severe hypothermia, immersion/trenchfoot, and frostbite, a serious injury that may require surgical amputation.

HIGH TERRESTRIAL ALTITUDE

In the continuing Indo-Pakistani conflict, the indigenous forces of these countries have been strategically located as high as 5,400 m. Combat personnel losses are estimated to be about 2,000 since the Siachen area became an active war zone in 1984 (5,16). An estimated 75% of these casualties have been attributed to weather and terrain (5,16).

Topographical data provide insight to the potential for altitude-related injury. Approximately 5% of the global land area lies at elevations in excess of 3000 m where serious altitude illnesses can occur. Although the total land surface area above 10,000 ft is quite small, major mountain ranges frequently define political boundaries that are likely areas of military conflict (e.g. the Andes, the Alps, and the Himalayas) (6). The largest contiguous high-altitude region lies in South Central Asia and includes the frequently contested border between China, Pakistan, and India (6). Physical performance decrements are caused by hypoxia, and incapacitating illnesses from exposure to high terrestrial altitudes include acute mountain sickness and two potentially fatal illnesses, high altitude pulmonary edema and high altitude cerebral

edema (1). Cold injury and solar radiation exposure risks are also increased in operations at high terrestrial altitudes (5,6).

OCCUPATIONAL PHYSIOLOGY AND PHYSICAL PERFORMANCE

Success of future military operations may largely be determined by the physical capacity and physical performance capability of the individual soldier. Inadequate physical training can reduce combat effectiveness through performance degradations. On the other hand, a high level of physical fitness can help to minimize the negative impact of such battlefield stressors as environmental extremes, combat stress, and sustained operations.

The development of a highly trained force can only be accomplished through innovative training programs targeted to the actual demands of physical tasks. Balanced and efficient physical training programs comprising optimal mixes of strength and aerobic training are needed to provide the rapid improvement in military task performance required on the modern battlefield. The following steps are necessary to produce a physically trained military force capable of performing physically demanding tasks: 1) establish the physical demands of battlefield tasks; 2) improve physical task performance through better selection, training, or modification; 3) determine the performance capacity of the soldier and match it to individual capacity; 4) develop methods of assessing physical task performance; and 5) identify and quantify the physiological, biomechanical, and body compositional determinants of task performance.

Research programs in physical performance are optimally suited to address problems facing the overloaded, rapidly deployed soldier who must perform in a multi-stressor environment. These programs are designed to improve the following: 1) soldier mobility through a better understanding of the physiological and biomechanical effects of such factors as speed, load, weight, load distribution, body composition, anthropometry, physical status, fatigue state, and surface/terrain features; 2) soldier load carriage capability, by utilizing biomechanical analysis to study load carriage variables, load carriage equipment, road march doctrine, performance determinants, training program specificity, and prevention of injuries; 3) soldier performance on other physically demanding tasks, such as repetitive lifting and litter carriage, by

biomechanical analysis of limiting factors and risk assessment for injury; and 4) physical performance and health, through development of weight and body fat standards.

OCCUPATIONAL MEDICINE

Musculoskeletal injuries negatively impact the Army mission during both peacetime and combat operations. During peacetime, injuries diminish combat readiness of units, detract from training and absorb valuable unit and medical resources. In times of conflict, non-battle injuries erode the fighting strength of the Army.

Injuries caused by training and operational activities are the most common medical problem of the peacetime Army many of which can be serious. During the 1980s, injuries resulted in 20,000 to 30,000 hospitalizations annually (25 to 35 hospitalizations per 1000 soldiers per year) resulting in 5 to 7 times as many days of limited duty as all infectious diseases (11). Injuries requiring hospitalization result in slightly more than 500 non-effective days per 1000 soldiers per year. Physical training and sports-related musculoskeletal injuries are the leading cause of hospitalization, accounting for over 12% of hospitalizations. Other physical activity-related injuries (marching, drilling, jumping, pushing, pulling etc.) account for another 12% of injuries. Hospitalizations represent only the tip of the injury iceberg. Many injuries, even those considered serious such as fractures and severe sprains, are treated on an outpatient basis. USARIEM studies indicate that 12 to 13 infantry soldiers per 100 per month seek medical care for musculoskeletal injuries, and these injuries on average result in more than 100 days of limited duty per 100 soldiers per month. The rates are slightly higher among male Army trainees with 14 to 15 per 100 trainees per month requiring medical care for injuries. For female trainees the rates of injury are higher still, 25 to 30 per 100 trainees per month. Approximately 50% of reported injuries result in one or more days of limited duty. Clearly, injuries pose a significant threat to the health of soldiers and to the combat readiness of units. Recent historical research on the influence of level of combat on the incidence of non-battle injuries and disease show that rates can be uniformly predicted to be higher during combat than during peacetime (14).

Non-battle injuries (NBI) also compromise the effectiveness of soldiers and units during armed conflicts. During World War II non-battle injuries caused almost 1 million, i.e., 969,230 U.S. soldiers to be hospitalized (15). Twenty percent of these NBI casualties were due to fractures and another 18% resulted from sprains. Overall NBI caused 2.7 times as many hospitalizations as all direct combat wounds and injuries in World War II. During the Korean conflict, NBI accounted for 16% of all hospitalizations compared to 23% for combat wounds, and in Vietnam, 14% of hospitalizations were due to NBI, while 17% were secondary to wounds and injuries sustained from combat (13). During Operation Desert Storm only 5% of the medical evacuations from the theater of operations were due to combat injuries, while 39% resulted from non-battle injuries (11). Data from past conflicts indicate that non-battle injuries significantly degrade the strength of military forces and impair the health of personnel.

MILITARY PERFORMANCE AND NEUROSCIENCE

Disease and environmental injury have historically accounted for 35-50% of combat casualties and lost combat duty time. Since stress-induced immune-suppression increases susceptibility to disease and delays recovery from disease and injury, the incidence and operational significance of these casualties could be minimized by reducing operational and environmental stress (4). Psychiatric illness has accounted for another 15-25% of combat casualties and lost combat duty time (4). The majority of these casualties are straightforward combat stress reactions, which would not occur if operational stressors were reduced (3). It is worth noting that many of these diseases, injuries and psychiatric disorders have long-term consequences. The cost of DoD and VA health care could be significantly reduced by minimizing the incidence of non-battle injury.

Friendly-fire fatalities are frequently the result of human error. Similarly, a substantial percentage of battle injuries is the result of stress-induced impairments in judgment or vigilance (4). Performance on the battlefield could be improved by implementing behavioral, nutritional, and pharmacological strategies to reduce the impact of operational and environmental stressors. This would not only reduce the incidence of battle injury, but would also improve the likelihood of successfully completing the mission.

ROLE OF MILITARY MEDICAL PERFORMANCE RESEARCH

Military personnel are regularly exposed to a vast array of stressors that are inherent to military operations: danger, death, heavy exercise, sleep loss, food restriction, lack of privacy, primitive living conditions, separation from family, culture shock, and role conflicts (e.g., peacemaking without disarmament). These operations are often accomplished in a context of extreme urgency requiring extended exposure to harsh environments with minimal protection. There are few civilian equivalents to this multi-stressor environment (4).

Limited information about performance under these conditions can be ethically and realistically gathered in a laboratory. Gathering such data in the field requires extensive liaison with military personnel and exposes investigators to many of the same hazards their "subjects" endure. The military-unique and critical nature of this information require that the DoD maintain a corps of scientists and an active program in this area.

USARIEM scientists are tasked with defining the problem in the field; that is, assessing the degree and significance of impairment in military performance induced by exposure to operational and environmental stressors. They are also required to answer basic science questions on how stressors produce deficits in health and performance. Methods from psychology, physiology, biochemistry, immunology, and endocrinology must be applied in an integrated fashion to determine how specific subsystems are affected by stress. Responsibility does not stop there, however. USARIEM scientists must convert their knowledge of underlying mechanisms into practical solutions for reducing the impact of stress on military performance. Behavioral, nutritional, and pharmacological solutions must be developed and evaluated.

USARIEM has unique capabilities that facilitate studying military performance under stress. The Military Performance and Neuroscience Division is unusual in its ability to integrate basic and applied science programs. The division's research psychologists are a part of an interdisciplinary team of Institute scientists who have access to large-scale military training exercises in which intellectual and physical performance can be assessed in conjunction with biochemical, immunological and

endocrinological variables. The Institute's environmental and hypobaric chambers are capable of reproducing any climate on the planet. Thus, research psychologists are able to return to the lab and reproduce components of the operational setting under controlled conditions, in order to test the safety and effectiveness of proposed interventions. Research psychologists use the division's state-of-the-art neuroscience laboratories to study animal models of the neurobehavioral, neurochemical, neuroanatomical, and neurophysiological consequences of stress. These integrated animal models permit research psychologists to isolate the influence of specific stressors on the brain, to test hypotheses about the underlying mechanisms of stress-induced performance deficits, and to develop strategies to reduce adverse neurochemical and neurophysiological reactions to stress.

MILITARY NUTRITION

One facet of medical threat described in the Medical Science and Technology Master Plan characterizes the following consequence: severe mental and physical performance degradation may be caused by energy and fluid deficiencies under the environmental extremes of the battlefield. The success of military operations may be determined by which force does the better job of minimizing the negative impact of the battlefield extremes of heat, cold, high altitude, combat stress, and sustained operations.

Nutritional deficiencies (e.g., energy → carbohydrate → glycogen) can be prevented and treated only by food or nutrient supplements. The best medical prophylaxis is food itself. The tailoring of the nutrient composition of the diet can address environmental and battlefield stress and help prevent performance decrements.

Military nutrition research is focused upon the needs to improve and sustain individual soldier physical and mental performance during military operations despite the hazards of the combat environment. Soldier sustainment utilizing improved nutrition tailored to the battlefield environment can increase tolerance for stress induced by physical and mental fatigue and by extremes of heat, cold, and high altitude. Military nutrition research is aimed at developing strategies to maintain soldier health as well as enhancing soldier performance. Research is designed to test

the efficacy of nutritional supplements in military operational situations. The overall goal is to optimize physical fitness and nutrition to perform military tasks. To address these issues, USARIEM is conducting research on nutritional strategies to enhance physical and mental military task performance, and on fluid and electrolyte requirements for Nuclear, Biological and Chemical operations and hot weather operations, evaluating the Army Field Feeding System in environmental extremes and promoting peacetime soldier wellness through diet and cardiovascular awareness.

GOALS

USARIEM's principal goal is to elucidate complex interactions of environmental stress and the body's defense mechanisms. From such information we propose, develop and evaluate techniques, equipment, and procedures most effective in ensuring that soldiers are operationally successful. Other goals include developing biomedical techniques to sustain health and enhance soldier performance through advances in physical fitness, exploiting nutritional strategies, pharmacological interventions, ergogenic aids, and other novel biotechnological approaches. Additionally, the Institute conducts physiological assessments of medical defense measures developed to protect against chemical battlefield threats.

While the goals of the Institute have subtly changed over the years in keeping with evolving Army roles and missions, early objectives remain important. In fact, one could argue that this mission is even more relevant for the warfighter of the 21st century than it was in the past. Army Field Manual (FM-100-5, June 1993) now devotes an entire chapter to the importance and influence of environmental extremes on combat operations. Statements from this chapter such as "U.S. Army forces must be prepared to fight and win on short notice anywhere in the world, from blistering deserts to frigid wastelands, in rain forests, tundra, mountains, jungles and swamps, urban sprawl and all types of terrain in between" lay testament to the importance of USARIEM's mission and goals.

SCIENTIFIC STAFF/ORGANIZATION

One of USARIEM's most important assets is its multi-disciplinary staff of approximately 160 individuals including over 50 Ph.D. scientists, board certified physicians and veterinarians. These scientists are internationally recognized for their technical and scientific accomplishments. Collectively, USARIEM has more than 1,500 scientific publications in environmental-exercise biology/physiology. In addition, USARIEM has by far the largest group of human environmental scientists located at any single institution in the world. This intellectual 'critical mass' combined with excellent research facilities gives USARIEM the unique capability to rapidly respond to unanticipated DoD taskings.

Over the years USARIEM's staff has become internationally recognized in a number of research areas or 'core competencies' including the area of environmental physiology and medicine, around which the Institute was founded. Other areas include environmental pathophysiology, comparative physiology, and most recently, a strong emphasis on occupational physiology and medicine.

For example, during Operation Desert Shield/Storm, USARIEM conducted six tasked studies, answered 13 formal information requests, held multiple consultations, and wrote several guidance documents (updated FM-3-4, contributed to Technical Notes 90-1 and 90-2). Recently, USARIEM has provided written guidance for deployment to Somalia (heat stress problems) and possible deployment to the former Yugoslavia (cold & altitude). No university, private company or other government (U.S. or foreign) laboratory has the staff, facilities or unique military knowledge to even remotely match these capabilities in the environmental physiology/medicine domain.

The close association of USARIEM with NRDEC provides a combined knowledge and technical expertise in clothing systems, thermal biophysics, biomedical engineering, biophysical mathematical modeling that is unequalled anywhere. This synergistic consolidation of technical staff of both research organizations, provides a Center of Excellence for soldier systems. The NRDEC has been designated as the Soldier Integration Center. Although individual universities and laboratories throughout the world could be called upon to address narrower problems, the special requirement

of a critical mass of scientific expertise for rapid information access in time of need can only be fulfilled by scientists collocated and doing research at Natick.

In order to most effectively utilize its research staff's expertise, USARIEM is organized into three research directorates: Environmental Pathophysiology, Environmental Physiology and Medicine, and Occupational Health and Performance. These directorates conduct technology-based research, accentuate multi-disciplinary approaches to problem solving, and seek out leveraged collaborative work with intraservice and interservice organizations to accomplish USARIEM's mission.

FACILITIES

NATICK CLIMATIC CHAMBER COMPLEX

Scientists at USARIEM have access to the NRDEC Doriol Climatic Chambers Complex which has been declared a 'national asset' by the U.S. Congress. These are the largest human research climatic chambers in the world. A 19 million dollar renovation of these facilities is now being completed. Within this complex there are two large chambers (110 m³) that can simultaneously house 12 subjects living at simulated hot or cold extremes for indefinite periods. In addition, there are two other smaller climatic chambers in the Doriol complex. Within this complex, climatic conditions can be precisely controlled -57°C to +74°C with winds from 0.8 to 64 kph, a capability which cannot be duplicated anywhere else in the United States. These facilities are used by USARIEM to conduct its own medical mission as well as to support clothing developers from NRDEC and the other two services in accordance with AR 40-7.

USARIEM CLIMATIC CHAMBERS

USARIEM has state-of-the-art climatic control chambers for human and animal experimentation. Scientists have on-site access to 13 climatic chambers -10°C to +50°C, one water immersion laboratory +5°C to +45°C, 36,000 liters and two hypobaric chambers -35°C to +43°C, barometric pressure equivalent to 8848 m. Five of these climatic chambers have recently undergone complete renovation. Included is

the only human-rated hypobaric chamber facility in the United States, capable of controlling both altitude and thermal conditions. This allows the study of combined stressors such as cold and altitude as they naturally occur. In addition, this hypobaric facility is the only one in the world that can simulate conditions of barometric pressure and ambient temperature and dewpoint for elevations as high as Mount Everest, i.e., (8,848 m). USARIEM also has one of the very few chambers which can be used to rapidly change climatic conditions (ramps), which is useful for specific clothing and physiological studies.

OTHER UNIQUE FACILITIES

There are several other physical resources available for joint Tri-Service efforts that are only available within USARIEM or NRDEC. These include sweating thermoregulatory hot plates, computer-controlled, regionally heated copper hands, copper feet, and articulated life-size manikins to evaluate fabrics (with a specially constructed climatic chamber), specific fibers, and materials from basic samples to total systems (handwear, footwear, and specialty clothing). Sectional and articulated copper manikin evaluations of thermal resistance yield vital predictions of heat loss from humans. These provide DoD with the core resources necessary for the effective development of reliable predictive models of soldier performance. These facilities have been repeatedly used in Tri-Service efforts to establish potential cooling efficiency as a function of local thermal resistances in a variety of clothing and vehicular systems.

ACCOMPLISHMENTS/IMPACT

For its efforts and accomplishments directly impacting U.S. fighting forces, USARIEM has received many expressions of customer satisfaction and commitments of continued support for its efforts. Over the years, USARIEM has established a reputation throughout DoD for providing timely, soldier-oriented, preventive medicine solutions to problems encountered with deployment to naturally harsh environments.

In August 1990, when Saddam Hussein invaded Kuwait, then Commander of the USARIEM, Colonel Gerald Krueger, assembled his staff and he challenged them

to provide the most critical medical guidance to U.S. forces deploying to the Kuwaiti Theater of operations. Initially, a 16-page summary paper entitled "Environmental Medicine Support for Desert Operations Practical Guidance and Suggestions for Deployment and Survival" was prepared. Subsequently, this document was distributed widely and served as a key source of information by other services as well as NATO forces. Later, a request was received from the Office of the Deputy Chief of Staff for Personnel, dated 30 October 1990, Subject: Distribution of Medical Information to Deploying Units, the staff of the USARIEM then produced USARIEM Technical Note 91-1, Sustaining Health and Performance in the Desert Environmental Medicine Guidance for Operations in Southwest Asia, 1 December 1990. Copies of this guidance were distributed to the Army Staff, Major Commands and deploying units. Then Vice Chief of Staff of the Army, General Gordon Sullivan responded with a second challenge to USARIEM. Reduce this technical note to a pocket-size document for platoon leaders and platoon sergeants to disseminate this critical information to their soldiers. On 19 December 1990 this Battle Dress Uniform pocket-size document, USARIEM Technical Note 91-2, was produced and distributed and has since been credited as an important factor in the extremely low incidence of heat casualties during those operations.

Since the distribution of this first deployment guide for sustaining health and performance in harsh environments, USARIEM has established a tradition of providing timely information to deploying units. The focus of this information has been to sustain, protect and enhance the health and performance of the warfighter across the operational continuum. Following the original deployment guide for Operation Desert Shield/Storm, USARIEM has produced several additional deployment guides. The deployment manual, "Sustaining Soldier Health and Performance in Somalia," was distributed to deploying troops in December of 1992. Well over 20,000 of these manuals were created, printed and distributed within three weeks of tasking, to the soldiers of the Operation Restore Hope Joint Task Force. For the expedient completion and the operational impact of this mission, USARIEM has been commended.

The USARIEM deployment manual, "Sustaining Health and Performance in the Cold," was distributed to units throughout the Army. In January of 1993, a related manual, "Sustaining Health and Performance in the Former Republic of Yugoslavia,"

was distributed to units in Germany and Yugoslavia in anticipation of cold weather operations in the Former Republic of Yugoslavia. Units in Alaska have also received this manual. Most recently, a deployment manual, "Sustaining the Health and Performance in Haiti," has been completed and distributed to troops deploying in this area. In addition USARIEM has prepared and distributed medical officer's handbooks which provide the latest guidance for medical personnel/staff regarding the prevention, identification, and treatment of heat, cold, and altitude injuries/illness.

The theme of protecting, sustaining and enhancing the health and performance of warfighters is not limited to training manuals or medical handbooks. The following accomplishments are indicative of the USARIEM research focus and impact in sustaining the soldier-system.

- Demonstrated that a molded plastic air and foam filled, outside-the-boot ankle brace reduces the incidence and severity of parachute jump injuries. In nine Fort Benning airborne classes, candidates wearing the brace (22,000 jumps) reported 52% fewer ankle sprains and 80% fewer ankle fractures. Testing continues with the 82nd Airborne Division and 10th Special Forces (SF) Group jumping with full tactical loads.

- Conducted two multi-agency, multi-disciplinary studies to medically assess the Army's 8-week Ranger training and qualification course. These studies demonstrated that a modest dietary modification (15% increase in calories provided) decreased weight loss of Ranger trainees, markedly reduced decrements in body composition, metabolism and immune function, and decreased medical attrition. As a result of USARIEM's recommendations, the Ranger Training Brigade implemented effective changes such as adding physician assistants to the staff of each training center, implementing medical monitoring and prophylactic improvements, and increasing the food supplied during summer Field Training Exercises.

- Determined that stresses of the Fort Bragg SF Assessment and Selection Course resulted in a 6% decrease in body weight, a 26% reduction in body fat and significantly suppressed immune function, increasing the risk of infection. Further research is planned. John F. Kennedy Special Warfare Center & School

(JFKSWC&S) is currently making course adjustments as a result of these important findings.

- Developed road march-time estimate tables for the JFKSWC&S to provide planners with estimates of maximal effort road march times for SF soldiers carrying heavy loads.
- Demonstrated a front-and back-of-body carrying pack reduces the risk of injury, back discomfort, and energy requirements in SF soldiers carrying heavy loads, compared to the standard Army issue backpack
- Demonstrated a liquid carbohydrate supplement increased physical performance (run-to-exhaustion times) in SF soldiers consuming energy-dense high-fat rations in a collaborative study conducted at the Louisiana State University Pennington Research Center
- Demonstrated that oral melatonin, a pineal gland hormone, may be an important stabilizer of sleep schedules in rapid deployment and continuous operations. Melatonin treatment of SF air and ground aviation crews prevented vigilance decrements and permitted longer sleep. This study was done in collaboration with members of the U S Army Aeromedical Research Laboratory and the 160th SF Aviation Task Force
- In an ongoing study of heat illness among Parris Island Marine Corps recruits, identified new and unexpected significant risk factors for exertional heat illness. Of particular significance were the discoveries that the activity and weather conditions on the preceding day were important predictors of the risk of illness, and that female recruits have laboratory evidence of heat illness without the dramatic clinical presentation found in male recruits. These findings help to establish practical methods for injury or illness intervention/prevention. This pioneering work is being accomplished in collaboration with members of the Uniformed Services University of the Health Sciences and the Marine Corps Training Center at Parris Island
- Examined glycerol ingestion as a "hyperhydrating" ergogenic aid to delay the development of dehydration and sustain health and performance in extreme

environments. Laboratory and field experiments begun in FY 92 will continue through FY 95.

- Compared thermoregulatory responses and performance of soldiers in Mission Oriented Protective Posture and Soldier Integrated Protective Ensemble (SIPE) during NBC Operations in support of NRDEC Advanced Technology Demonstration (ATD). Provided expertise to Program Manager-SIPE for component selection and ATD test plan development. USARIEM co-investigators assisted in the SIPE-ATD field demonstration at Fort Benning. In addition, USARIEM conducted an independent study validating earlier findings
- Completed heat strain prediction modeling of the U.S. Army Aircrew Uniform Integrated Battlefield flightsuit over an Aircrew Microclimate Conditioning System for NRDEC and Army Materiel Command
- Completed copper manikin and heat strain modeling on NATO chemical protective ensembles for The Technical Coordination Panel member nations who now use USARIEM's data base for forecasting. Established the Test Operational Procedure agreed upon for subsequent thermal strain evaluation of candidate uniforms by these five English speaking nations
- In cooperation with NRDEC and the Technology Base Executive Steering Committee Soldier System Modeling Work Group, a high temporal resolution thermal strain prediction model is being implemented within the Integrated Unit Simulation System (IUSS). This capability will permit evaluation of multiple stressors on individual and small-unit performance in a wide range of military scenarios

The IUSS models the environmental and occupational health impacts on individuals and units engaged in military operations. The IUSS predicts the skin and core temperature and the heart rate, and extrapolates the percentage of individual and unit degradation in a battlefield operating system task scenario. Today this modeling system allows the tactical commander to simulate missions and to better understand the human element, the soldier. Another reality of the IUSS is the fact that the most critical system on the battlefield is the soldier-system. The most sophisticated weapon

systems in today's battlefield are incomplete without the sustainment of the health and performance of the individual warfighter who operates them.

Today the IUSS performs mission simulations in both stand-alone and distributed integrated simulation compliant modes. In the future, IUSS, or a similar system, will be of great value to the tactical commanders who will be able to utilize this real-time planning information. These technical advances will move U.S. forces closer to "owning the environment." Course of action analyses will be enhanced to a new dimension, since the level of sophistication in intelligence preparation of the battlefield (IPB) increases directly. The result will be that the tactical commander will be able to more accurately predict individual and unit performance capabilities. An added value will be to identify the most opportune time to commit U.S. forces and influence the outcome of the operation. Incorporating the impact of ergogenic aids to IUSS will provide another level of sophistication and further enhance the capabilities of the tactical commander.

The unique collocation of NRDEC engineers and USARIEM biologists and physicists has resulted in the development of a sophisticated system to evaluate the potential thermal strain of clothing systems. Numerous advanced clothing evaluation/thermal modeling efforts fulfilled for the Tri-Services provide cost-effective benefits to the government: 1) The developer can reduce the number of redundant military clothing prototypes required to field personnel, 2) Textile items can be utilized for multiple model tests during a given selection process, 3) Rapid access biophysical evaluations using specific thermal devices allow all the DoD Services to be kept informed as to what is available in the commercial market should current stockpiles of handwear, footwear, and clothing items need to be supplemented during large scale mobilizations, 4) Natick Combined Laboratories' unique role in offering technical expertise as an independent DoD contract evaluator allows disinterested technical judgement on many contract resolutions.

SUMMARY

USARIEM staff and facilities coupled with the NRDEC Doriot Climatic Chamber Complex provide a world class resource to study and develop countermeasures to

environmental and occupational threats to U.S. forces. The Institute and its staff are held in high esteem by industry, academia, and other government laboratories. This is true because USARIEM has the only broad-based and integrated program (engineering, performance physiology with prediction modeling) capable of solving the complex problems relating to military deployment and operations in stressful environments.

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